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Investigation the effect of Different Types of Fuzzy Controllers in Relieving the Sensitivity to Seismic Excitation of an 11-Story Structure with an Active Mass Damper

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ABSTRACT: The application of active tuned mass damper (ATMD) has been considered to control the seismic responses of the building in recent years. LQR and PID are two common methods in classical structural control. Both methods are sensitive to the input signal (seismic excitation). Therefore, in this study, the efficiency and effectiveness of three approaches are investigated to estimate the control force of ATMD; (1) fuzzy-LQR, (2) fuzzy-PID, and (3) fuzzy logic controller. The first and second ones are the combination of the linear quadratic regulator (LQR), and proportional–integral–derivative (PID) with fuzzy logic controller (FLC). The Observer-Teacher-Learner-Based Optimization algorithm (OTBLO) is utilized to enhance the performance of FLC. The fuzzy membership functions for inputs are tuned and fuzzy rules are extracted to find out the proper control force to reduce the peak seismic response of a structure. In this study, five control criteria, including maximum displacement, maximum acceleration, maximum Inter story drift, base shear force and base moment for the performance of each control system, are evaluated. An 11-story building which is equipped by ATMD with three active control systems including fuzzy-LQR, fuzzy-PID, and fuzzy logic controllers subjected to different earthquakes. The results show that, although three optimized controllers can effectively reduce the peak seismic response of the building, the performance of the fuzzy logic controller is slightly better than two other hybrid controllers to reduce seismic responses. The results show that the three active controllers reduce the structural responses by an average of 9 to 28% compared to the uncontrolled state in various earthquakes and can effectively reduce the seismic response of the building, while the performance of the fuzzy logic controller to reduce seismic responses is slightly better than the other two combined controllers.

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1- Introduction

Structural vibration control methods are the most recent strategies to protect civil structures from excessive vibration, caused by environmental dynamic loads (i.e., wind and earthquake). They are classified into several devices including active, semi-active, passive and hybrid systems [1].

For several years great efforts have been devoted to the study of using Tuned mass dampers (TMDs) to protect civil structures [2-4]. A key limitation of using TMDs is that correctly calculating the fundamental frequency of vibration in a structure is impossible because of the uncertainty in the specification of structural models. Also, the effectiveness of TMDs for reducing the structural response is in a narrow range of load frequencies. Therefore, converting them to an active or hybrid system can enhance their efficiency [5].

One case of active system is Active Tuned Mass Damper (ATMD) including TMD, sensors, and actuators to protect structures against earthquake. Proportional–integral–derivative (PID) and linear quadratic regulator (LQR) are useful algorithms in modern control theory, which has been studied by several researchers to control an active control device [6-10]. The most drawback of LQR is that LQR algorithm performs based on an optimum value of Q and R for each earthquake. It means that the LQR algorithm is extremely sensitive for input signals (earthquakes). Previous studies indicate that the performance of PID generally depends on earthquakes as input signals for control systems. Since different earthquakes have different frequency spectrums, there is no guarantee to tune a PID controller for performing well under other earthquakes. Therefore, using fuzzy logic with PID as well as LQR algorithms can be useful to control structures under seismic excitations. Fuzzy Logic Controller (FLC) is one of the effective approaches to estimate the control force, generated by ATMD. It is used as a

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reference to adjust appropriate control force. One of the most significant considerations in designing FLC is the creation of the membership functions for each linguistic variable, as well as the rule base. In most available applications, the fuzzy rules are generated by an expert in the area, especially for control problems with only a few inputs, but with an increasing number of inputs and linguistic variables, it is too difficult for experts to describe a complete set of rules and associated membership functions for suitable application of Fuzzy Logic Controller [11]. Using optimizing algorithms is extremely effective in overcoming the mentioned difficulties, which contain tuning membership functions and rules.

In this study, an 11-story building equipped with one ATMD is investigated. To find out the control force generated by ATMD, three different controllers including fuzzy logic controller, LQR and PID are used. Also, fuzzy logic is applied to improve the performance of LQR and PID controllers. Observer-Teacher-Learner-Based Optimization (OTBLO) is utilized to optimize the membership functions and rules of FLC and hybrid fuzzy logic with both LQR and PID algorithms to enhance the performance of them. Fuzzy membership functions for inputs are tuned and fuzzy rules are extracted in order to find the appropriate control force to reduce the peak seismic response of the building.

2- Numerical study

The numerical simulations of the seismic responses of the structure are performed within MATLAB software. In this study, three different controllers including fuzzy logic controllers (FLC), hybrid fuzzy logic with LQR (fuzzy-LQR) and hybrid fuzzy logic with PID (fuzzy-PID) are employed to estimate the control force, which generated by ATMD. The Gaussian membership function is defined for input variables (displacement and velocity) in all three controllers and the triangle membership function is specified for output variable including the control force of ATMD, feedback gain matrix (k_c,k_i and k_d) and feedback gain matrix for FLC, Fuzzy-PID and Fuzzy-LQR respectively. OTBLO is used to optimize the three controllers in an 11-story building, which is equipped with one ATMD. To reduce the peak seismic response of the building (maximum displacement), fuzzy membership functions (Gaussian MF) for input variables are tuned and fuzzy rules are extracted in order to find out the appropriate ATMD' force. Floor masses of the structure are identical and horizontal story stiffness is uniform as well. The structural parameters of the building are obtained from [12]. Rayleigh damping and TMD dynamic parameters are selected based on Purzeynali et al. research paper [12]. Four earthquakes are used to optimize FLC of all controllers based on minimization of the peak displacement value of the top floor of 11-story building, which one ATMD is installed at the top story under some earthquake excitations considered is calculated as follows,

$$MinimizeZ = \frac{(z_2 - z_1)}{(z_1)} \quad (1)$$

where z_1 and z_2 are Root-Mean-Square Deviation (RMSD) of maximum uncontrolled displacement and maximum controlled displacement of the top story for different earthquakes.

3- Robustness of designed control systems

For verifying the robustness of the optimal control system, the structural responses, which obtained from different optimal control systems like as TMD, FLC, fuzzy-PID and fuzz-LQR. Five criteria are represented to estimate the performance of three control systems. The criteria are based on peak displacement, acceleration level, inter-story drift ratio, base shear and base moment, which compare controlled responses to uncontrolled ones.

The main point in the studies is that LQR and PID methods are very sensitive to the input signal (earthquake). To overcome this issue in this study, the optimized fuzzy controller is combined with two methods. Then several different earthquake records were applied to the 11-story structure with all control systems. With this approach, the sensitivity of LQR and PID methods to the input signal (earthquake record) is greatly reduced. This means that two hybrid systems with the fuzzy controller are able to decrease the structural responses, including peak displacement, acceleration level, inter-story drift ratio, base shear and base moment subjected to various earthquakes in comparison with the uncontrolled state. Finally, the fuzzy control system has a relatively better performance in reducing structural responses than other systems.

4- Conclusions

In this paper, the performance of Active Tuned Mass Damper was investigated in an 11-story building. Three different controllers including Fuzzy Logic Controller, Fuzzy-LQR and Fuzzy-PID were used to control the building. Fuzzy logic was combined with LQR and PID in order to find better feedback gain matrixes to improve the performance of them. The design of fuzzy system was carried out based on the displacement and velocity of the structure. To enhance the performance of the controllers OTBLO algorithm was used to optimize the parameters of FLCs including the membership function and fuzzy rule set. Then, five criteria including peak displacement, level acceleration, the inter-story drift ratio, base shear and base moment were considered. The most important results are listed as follow:

All control systems including Fuzzy Logic Controller, Fuzzy-LQR and Fuzzy-PID were slightly successful to mitigate top story displacement, acceleration, and the maximum inter-story drift ratio, base-shear, and base-moment of the building in comparison with uncontrolled responses. Furthermore, optimal TMD could mitigate the five defined criteria.

It has been found that although the performance of the FLC, which is optimized based on top story displacement, is better than other controllers for reducing displacement, Maximum Inter story drift and base shear of structure, Fuzzy-LQR is better than FLC for reducing Maximum acceleration and base moment of the 11-story building. Analytical and simulation results indicate that Fuzzy-PID is slightly successful in reducing five defined criteria. By using a suitable controller to reduce the seismic responses of the building, these responses can be reduced by up to 50% compared to the uncontrolled state. Also, the average response reduction for all controllers is between 9 and 28%.

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